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HARMFUL EFFECTS OF ALDEHYDES IN SOILS.

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INTRODUCTION.

In the course of a study of the soils on the Mount Vernon estate, Virginia, large samples from the flower garden were subjected to a special examination in the laboratory. In this flower garden box hedges, roses, and other perennial garden plants have grown for years and manure has been liberally applied. The soil is a brown mellow loam containing enough sand and vegetable matter to effect an excellent structural condition. At a depth of about 15 inches the surface soil passes into a reddish brown to yellowish brown clay loam. This subsoil in turn grades into a compact red clay, faintly mottled in places with grayish colors, at a depth of approximately 24 inches. This layer of material resembles a hardpan formation. The compact condition undoubtedly affects the movement of moisture and air. The examination of the soil in the laboratory showed that the surface soil was acid and the subsoil decidedly so.

When subjected to the methods for isolating organic substances from soils as devised in this laboratory, saccharic acid, acrylic acid, mannite, and salicylic aldehyde were obtained. The details of the isolation of these compounds have already been reported¹ and only the salicylic aldehyde is of interest in the present paper. It was obtained as follows:

The soil was extracted with 2 per cent sodium hydroxide, and the solution thus obtained was acidified with sulphuric acid and filtered. The acid filtrate was shaken out with several portions of ether, the ether extracts being combined and shaken with a concentrated

¹ Shorey, E. C., Some Organic Soil Constituents, Bul. 88, Bureau of Soils, U. S. Department of Agriculture, p. 19 (1913).

NOTE.—This bulletin deals with the discovery and properties of aldehydes in soils. These are shown to affect crops unfavorably and decrease the yield greatly. The results are of interest to agricultural experimenters and those practical farmers whose training interests them in the advance of scientific agriculture.

aqueous solution of sodium bisulphite. The bisulphite solution was separated from the ether, strongly acidified with sulphuric acid, and air blown through to remove sulphur dioxide. This solution was then shaken with several portions of fresh ether, the ether extracts combined, and the ether removed by evaporation over a small volume of water. The solution remaining was filtered from a small quantity of resinous insoluble material and as thus obtained was a slightly colored solution having an aromatic odor and the properties of a solution of salicylic aldehyde. On slow evaporation of the water there was left a yellow oil, soluble in water with some difficulty, but very soluble in alcohol or ether. The water solution developed a pink color in fuchsine aldehyde reagent almost immediately and gave an intense violet color with ferric chloride. When treated with phenylhydrazine, a precipitate was formed which on recrystallization from alcohol was in the form of yellow leaflets that melted at 143° , the characteristic form and melting point of the phenylhydrazone of salicylic aldehyde. The separation of this compound from ether solution by an aqueous solution of sodium bisulphite and the color produced with fuchsine reagent fix it as an aldehyde. The general properties of the compound and the formation of the hydrazone melting at 143° are sufficient to identify it as salicylic aldehyde.

As the large sample of soil collected was used up in the above isolation and identification of some of its organic constituents, a second shipment of the soil was secured and sufficient salicylic aldehyde obtained to make some tests of its action on plants.

The effect of the soil aldehyde was tested on wheat by growing the plants in water cultures. An experiment was made with the aldehyde dissolved in pure distilled water. The wheat was grown in water in culture jars holding 250 c. c. One jar contained pure distilled water, and the second contained the water in which was dissolved the aldehyde separated from the soil. The plants grew for two weeks. The aldehyde was quite harmful, reducing growth about 37 per cent. Another experiment was made, using a good nutrient solution with and without the substance. The aldehyde from the soil was extremely harmful, even in the good nutrient solution; the green weight of the plants was reduced 40 per cent. These experiments with the salicylic aldehyde extracted from the soil on growth are shown in Plate I, figure 1. The plants show the harmful effect of the substance on growth. It will be seen that both tops and roots in nutrient solution and in distilled water are badly affected by the presence of the salicylic aldehyde.

Having thus demonstrated the harmful action of this substance when isolated from a soil, there remains a further study of the action of this compound on various plants and in various culture solutions,

in soils in pots, and finally in the field. For these further studies, which required quantities impossible of procuring from the soil itself, the chemically prepared salicylic aldehyde was used.

EFFECT OF SALICYLIC ALDEHYDE ON PLANTS IN SOLUTION CULTURES.

EFFECT ON WHEAT.

The method of growing wheat seedlings in solution cultures is fully described in previous bulletins.¹

Salicylic aldehyde was used in amounts of 10, 25, 50, 100, and 200 parts per million dissolved in pure distilled water. A culture of distilled water without salicylic aldehyde was included in the test and used as a control. The cultures grew from May 4 to May 16, 1912. It became at once apparent that the salicylic aldehyde was very harmful to the seedling wheat, even in the lowest concentration of 10 parts per million. The appearance of the series of plants on the sixth day is shown in Plate I, figure 2. In the culture solution containing 10 parts per million growth was reduced 31 per cent; in the 25 parts per million solution growth was reduced 69 per cent; with 50, 100, and 200 parts per million the plants were killed.

EFFECT ON CORN.

The effect of salicylic aldehyde on corn plants was tested by growing the corn in nutrient solutions of calcium acid phosphate, sodium nitrate, and potassium sulphate, with and without salicylic aldehyde.

The aldehyde was used in amounts of 10, 25, 100, and 200 parts per million. One corn plant was used in each culture jar containing 250 c. c. of the solution. The plants were germinated and put in the solution when they were about 1½ inches high. The corn grew in the solutions from May 26 to June 20, 1912. A photograph of the cultures, taken when the plants had been growing for 10 days, is shown in Plate II, figure 1. The harmfulness of this substance to corn is clearly shown. The effect was very noticeable, even in the culture containing 10 parts per million. In the culture containing 200 parts per million there was very little growth; the plants were almost dead.

In Table I are given the green weights of the plants, taken when the experiment was concluded. The last column indicates the relative growth.

TABLE I.—*Effect of salicylic aldehyde on corn in nutrient solutions of calcium acid phosphate, sodium nitrate, and potassium sulphate.*

No.	Treatment.	Green weight.	Relative growth.
		<i>Gram.</i>	
1	Nutrient solution.....	1.00	100
2	Same + 10 parts per million salicylic aldehyde.....	.60	60
3	Same + 25 parts per million salicylic aldehyde.....	.60	60
4	Same + 50 parts per million salicylic aldehyde.....	.21	21
5	Same + 100 parts per million salicylic aldehyde.....	.21	21
6	Same + 200 parts per million salicylic aldehyde.....	.10	10

¹ See especially Bul. 70, Bureau of Soils, U. S. Dept. of Agriculture.

The figures in the table show a decreased growth due to the salicylic aldehyde. Ten parts per million reduced growth from 100 to 60, or 40 per cent, 50 and 100 parts per million were also extremely harmful, and very little growth occurred in the 200 parts per million solution.

EFFECT ON COWPEAS.

An experiment with cowpeas, similar to that with corn seedlings, was made, using the same concentrations of salicylic aldehyde and the same nutrient solution. The plants grew in the solutions from June 15 to June 28. One plant was used in each culture.

The effect of the aldehyde on the cowpea plants was similar to that with wheat and corn. In Plate II, figure 2, are shown the plants as affected by the aldehyde. From this it is seen that amounts larger than 10 parts per million are extremely harmful to the cowpea.

In Table II is given the green weight of the cowpea plants taken at the end of the experiment, and their relative growth.

TABLE II.—*Effect of salicylic aldehyde on cowpeas in nutrient solutions.*

No.	Treatment.	Green weight.	Relative growth.
		<i>Grams.</i>	
1	Nutrient solution.....	1.35	100
2	Same + 10 parts per million salicylic aldehyde.....	1.35	100
3	Same + 25 parts per million salicylic aldehyde.....	.70	51
4	Same + 50 parts per million salicylic aldehyde.....	.35	26
5	Same + 100 parts per million salicylic aldehyde.....	.20	15
6	Same + 200 parts per million salicylic aldehyde.....	.15	11

The figures in the table show that salicylic aldehyde in amounts of 10 parts per million did not affect the green weight. The green weight was the same in that culture as in the nutrient solution which did not contain aldehyde. The culture containing 25 parts per million of the aldehyde, however, produced a much smaller plant than the control. The growth was reduced from 100 to 51. Solutions containing 50, 100, and 200 parts per million produced very poor plants. The plants made very little growth and were almost dead when the experiment was discontinued.

EFFECT ON CABBAGE.

An experiment in nutrient solution was made to determine the effect of the salicylic aldehyde on young cabbage plants. The nutrient solution was the same as that used with corn and cowpeas. The salicylic aldehyde was used in quantities varying from 10 to 200 parts per million. In each culture 10 young cabbage seedlings were grown. The plants were supported in the culture jar by means of a cork, similar to the manner in which the wheat seedlings were grown. The plants grew in the solution from May 25 to June 12, 1912. A

photograph of the cultures was taken when they had grown seven days, and is shown in Plate III, figure 1. Growth was materially reduced by 10 and 25 parts per million, while 50, 100, and 200 parts per million killed the plants. Cultures stronger than 50 parts per million are not shown.

When weighed at the termination of the experiment, growth in the culture containing 10 parts per million salicylic aldehyde was found to be reduced 39 per cent. With 25 parts per million growth was reduced 61 per cent. This shows that the aldehyde in small amounts was quite harmful to the young cabbage plants.

EFFECT ON RICE.

When tested on rice seedlings in water and in nutrient solutions the salicylic aldehyde was found to be harmful to this crop also. The distilled water solutions of 10 parts per million of salicylic aldehyde gave a depression of 16 per cent in the green weight of the plants. In the nutrient solutions the 10 parts per million of salicylic aldehyde gave a depression of 15 per cent in the green weight.

EFFECT OF SALICYLIC ALDEHYDE IN SOIL IN POTS.

EFFECT ON WHEAT.

Experiments were made to study the effect of salicylic aldehyde in soil. Paraffined wire pots¹ holding approximately 1 pound of soil were used. The soil was a heavy clay loam. Before potting, portions of the soil were treated with varying amounts of salicylic aldehyde. Six wheat plants were grown in each pot. The experiment was begun May 27 and discontinued June 18. In Plate III, figure 2, are shown the plants as they appeared near the end of the experiment. This shows that the salicylic aldehyde was harmful. The final results are given in Table III.

TABLE III.—*Effect of salicylic aldehyde on wheat plants in soil.*

No.	Treatment.	Green weight.	Relative growth.
		<i>Gram.</i>	
1	Clay loam untreated.....	0.65	100
2	Same + 10 parts per million salicylic aldehyde.....	.65	100
3	Same + 25 parts per million salicylic aldehyde.....	.50	77
4	Same + 50 parts per million salicylic aldehyde.....	.40	61
5	Same + 100 parts per million salicylic aldehyde.....	Dead.....	
6	Same + 200 parts per million salicylic aldehyde.....	Dead.....	

As seen from the table the aldehyde in amounts of 10 parts per million in the soil had no effect. Larger amounts than 10 parts per million were quite harmful. With 25 parts per million growth was

¹ Method as described in Circ. 18, Bureau of Soils, U. S. Dept. of Agriculture.

reduced from 100 to 77, or 23 per cent. With 50 parts per million the growth was reduced from 100 to 61, or 39 per cent. In amounts of 100 and 200 parts per million the plants were killed.

EFFECT ON CORN.

The action of salicylic aldehyde in soil and also in sand was tested as to its effect on corn. The aldehyde was added to a clay soil and to pure quartz sand in amounts of 50 parts per million. One pot each of the soil and sand untreated was run as a check. The corn was planted May 23 and grew until June 20. One corn plant was grown in each pot containing soil and two plants in each pot containing sand.

A photograph of the plants is shown in Plate IV, figure 1. The first two pots contain soil and the last two sand. Number 2 in each case had been treated with salicylic aldehyde. Growth in the treated pots is seen to be much smaller than the growth in the check pots. The effect of the salicylic aldehyde in the sand is seen to be greater than in the clay soil.

The green weight of the plants was taken at the termination of the experiment. The salicylic aldehyde was found to have reduced growth in the clay soil from 100 to 76, or 24 per cent, and in the sand from 100 to 40, or 60 per cent. The harmful effect was more marked in the quartz sand than in the clay soil, which is probably due to the absorptive power of the clay being far greater than that of the sand, and perhaps also to the higher nutritive value of the soil in comparison with the pure sand.

EFFECT ON CLOVER.

The clover was grown in an ordinary flower pot holding 6 pounds of soil, using a good loam soil, the Hagerstown loam. One pot was untreated, the other had a total of 100 parts per million of the salicylic aldehyde added to it.

When the soil was potted 50 parts per million of the aldehyde was added, and clover then sown, 0.5 gram of seed per pot. Later, when the clover was up, 25 parts per million more of the aldehyde was added in solution through a funnel passing into the soil nearly to the bottom of the pot, thus avoiding direct contact with the tops or roots of the clover. Three weeks later another 25 parts per million was added in the same manner. The experiment lasted from April 12 to June 21, 1912. From the beginning the effect of the aldehyde on the clover was noticeable.

In Plate IV, figure 2, is shown the appearance of the pots when the clover was well up. The inhibiting effect of the salicylic aldehyde is clearly shown. The control was of a deep green color, while the treated pot showed not only a poor growth, but also a much faded color, and had a decidedly unhealthy appearance.

The green weights taken at the termination of the experiment were 8.5 grams from the control pot and only 4.2 grams from the salicylic aldehyde treated pot, a decrease of approximately 50 per cent.

In the foregoing salicylic aldehyde has been shown to be harmful to wheat and rice seedlings in distilled water, to wheat, corn, cowpeas, cabbage, and rice in nutrient solutions, and to wheat, corn, and clover in soil in pots.

EFFECT OF SALICYLIC ALDEHYDE IN SOLUTION CULTURES WITH VARIOUS FERTILIZER INGREDIENTS.

EFFECT ON WHEAT.

The effect of salicylic aldehyde on wheat plants was further studied by growing the seedlings in nutrient culture solutions containing the ordinary fertilizer salts, calcium acid phosphate, sodium nitrate, and potassium sulphate. Some of the cultures contained calcium acid phosphate only, some sodium nitrate only, and some potassium sulphate only. Other solutions were composed of mixtures of two salts, calcium acid phosphate and sodium nitrate, calcium acid phosphate and potassium sulphate, and sodium nitrate and potassium sulphate. Still other solutions had all three constituents in various proportions. The compositions of the various solutions is given in the first three columns of the tables which are to follow.¹ Two sets of cultures were prepared; to one set were added merely the nutrient salts; to a similar set 10 parts per million of salicylic aldehyde were added in each culture in addition to the nutrient salts. The culture solutions were changed every three days, four changes being made in the course of the experiment. The solutions were analyzed for nitrates immediately after each change. The phosphate and potassium were determined on a composite solution of the four changes. The culture grew from May 15 to May 27, 1912.

When the plants had grown for several days, it was noticeable that the salicylic aldehyde cultures were developing more slowly. Each of the cultures seemed affected, regardless of the composition or the proportion of the nutrient salts.

When the plants had grown for 12 days with four changes of the solutions, the green weights were taken. The results obtained with the solution of different fertilizer ingredients are grouped in the tables which follow, so as to bring together those cultures which were composed principally of phosphate, those which were composed principally of nitrate, and those composed principally of potassium salt. In each group there were 21 cultures. A fourth group, comprising six cultures, is also given. It includes those cultures with a nearly equal proportion of the three salts.

¹ The solutions were prepared as described in Bul. 70, Bureau of Soils, U. S. Dept. of Agriculture.

Table IV gives the growth in cultures composed principally of phosphate, without and with 10 parts per million of salicylic aldehyde. The composition of the culture solution is given in the first three columns. As will be seen, the solutions contained principally phosphate, but also varying smaller amounts of nitrate and potash. In the fourth column is given the green weight of the plants grown in solutions which contain no salicylic aldehyde, and in the fifth column the weight of the plants in solutions containing 10 parts per million of salicylic aldehyde.

By comparing these two columns in the table it is seen that the green weight of the salicylic aldehyde culture is less in every case, with one exception only, than the green weight of the culture of the same fertilizer mixture without the salicylic aldehyde. The total green weight of the 21 normal, or control, cultures was 39.61 grams, against 31.74 grams for the 21 cultures with salicylic aldehyde.

TABLE IV.—*Effect of salicylic aldehyde on wheat in nutrient culture solutions composed principally of phosphate.*

Composition of culture solution.			Without salicylic aldehyde.	With salicylic aldehyde, 10 parts per million.	Composition of culture solution.			Without salicylic aldehyde.	With salicylic aldehyde, 10 parts per million.
P ₂ O ₅	NH ₃	K ₂ O	Green weight.	Green weight.	P ₂ O ₅	NH ₃	K ₂ O	Green weight.	Green weight.
<i>Parts per million.</i>	<i>Parts per million.</i>	<i>Parts per million.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Parts per million.</i>	<i>Parts per million.</i>	<i>Parts per million.</i>	<i>Grams.</i>	<i>Grams.</i>
80	0	0	1.02	0.76	48	8	24	2.50	1.54
72	0	8	1.32	1.04	48	16	16	2.60	1.92
72	8	0	1.30	1.14	48	24	8	2.50	1.88
64	0	16	1.32	1.22	48	32	0	1.64	1.34
64	8	8	1.70	1.44	40	0	40	1.75	1.10
64	16	0	1.54	1.14	40	8	32	1.90	1.52
56	0	24	1.24	1.38	40	16	24	2.98	2.16
56	8	16	2.34	1.52	40	24	16	2.88	2.14
56	16	8	2.04	1.66	40	32	8	2.28	1.74
56	24	0	1.34	1.28	40	40	0	1.80	1.60
48	0	32	1.62	1.22					

Table V gives the results of salicylic aldehyde in nutrient solution in which the principal ingredient is nitrate.

As seen in the fourth and fifth columns of the table, the growth in cultures with salicylic aldehyde are much smaller than the growth in solutions containing merely the nutrient salts. The total green weight of the 21 cultures in nutrient salts was 49.36 grams, and the green weight of the 21 nutrient cultures containing 10 parts per million salicylic aldehyde was only 36.11 grams. From these figures it is seen that salicylic aldehyde in these nutrient solutions, principally nitrogenous, as in the phosphate solutions, is quite harmful to wheat plants.



FIG. 1.—EFFECT OF SALICYLIC ALDEHYDE EXTRACTED FROM MOUNT VERNON GARDEN SOIL ON WHEAT SEEDLINGS.

- (1) Nutrient solution; (2) nutrient solution plus salicylic aldehyde; (3) distilled water; (4) distilled water plus salicylic aldehyde.

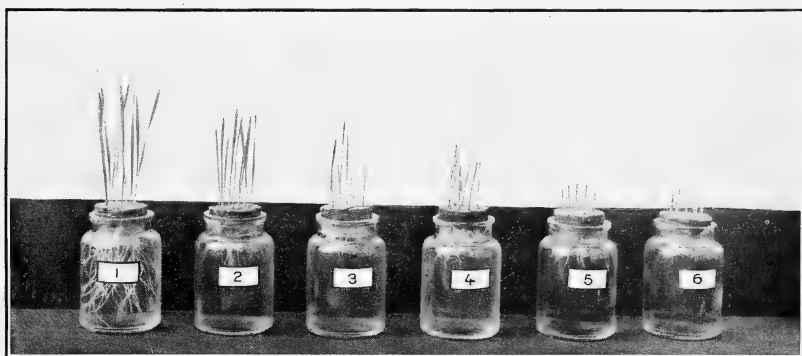


FIG. 2.—EFFECT OF SALICYLIC ALDEHYDE ON WHEAT SEEDLINGS IN WATER SOLUTIONS.

- (1) Control in distilled water; (2) same plus salicylic aldehyde 10 parts per million; (3) 25 parts per million; (4) 50 parts per million; (5) 100 parts per million; (6) 200 parts per million.

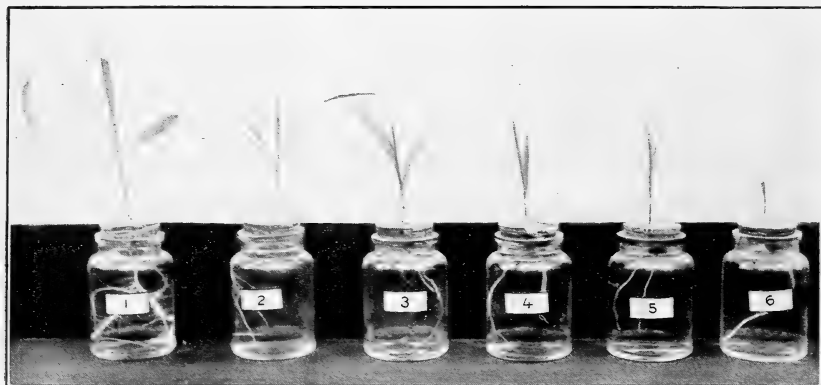


FIG. 1.—EFFECT OF SALICYLIC ALDEHYDE ON CORN IN NUTRIENT SOLUTIONS.

(1) Control in nutrient solution; (2) same plus salicylic aldehyde 10 parts per million; (3) 25 parts per million; (4) 50 parts per million; (5) 100 parts per million; (6) 200 parts per million.

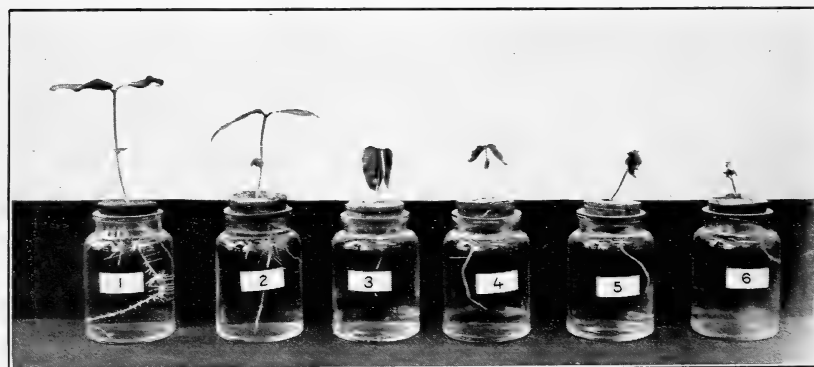


FIG. 2.—EFFECT OF SALICYLIC ALDEHYDE ON COWPEAS IN NUTRIENT SOLUTION.

(1) Nutrient solution; (2) same with 10 parts per million salicylic aldehyde; (3) 25 parts per million; (4) 50 parts per million; (5) 100 parts per million; (6) 200 parts per million.



FIG. 1.—EFFECT OF SALICYLIC ALDEHYDE ON CABBAGE SEEDLINGS IN NUTRIENT SOLUTIONS.

(1) Nutrient solution; (2) same plus 10 parts per million salicylic aldehyde; (3) 25 parts per million; (4) 50 parts per million.



FIG. 2.—EFFECT OF SALICYLIC ALDEHYDE ON WHEAT IN SOIL.

(1) Clay soil; (2) same plus salicylic aldehyde 10 parts per million; (3) 25 parts per million; (4) 50 parts per million; (5) 100 parts per million.



FIG. 1.—EFFECT OF SALICYLIC ALDEHYDE ON CORN IN SOIL AND SAND.

(1) Clay soil; (2) same plus 50 parts per million salicylic aldehyde. (1) Sand; (2) same plus 50 parts per million salicylic aldehyde.



FIG. 2.—EFFECT OF SALICYLIC ALDEHYDE ON CLOVER IN SOIL.

(1) Soil untreated; (2) soil with a total of 100 parts per million of salicylic aldehyde.

TABLE V.—*Effect of salicylic aldehyde on wheat in nutrient culture solutions composed principally of nitrate.*

Composition of culture solution.			Without salicylic aldehyde.	With salicylic aldehyde, 10 parts per million.	Composition of culture solution.			Without salicylic aldehyde.	With salicylic aldehyde, 10 parts per million.
P ₂ O ₅	NH ₃	K ₂ O	Green weight.	Green weight.	P ₂ O ₅	NH ₃	K ₂ O	Green weight.	Green weight.
Parts per million.	Parts per million.	Parts per million.	Grams.	Grams.	Parts per million.	Parts per million.	Parts per million.	Grams.	Grams.
0	80	0	1.80	1.31	8	48	24	3.12	1.60
0	72	8	2.00	1.60	16	48	16	2.74	1.74
8	72	0	1.86	1.30	24	48	8	2.34	2.00
0	64	16	2.00	1.50	32	48	0	1.80	1.56
8	64	8	2.50	1.84	0	40	40	2.50	1.54
16	64	0	1.76	1.40	8	40	32	3.44	2.12
0	56	24	2.04	1.74	16	49	24	3.00	2.10
8	56	16	3.00	1.78	24	40	16	2.70	2.10
16	56	8	2.24	2.04	32	40	8	2.20	1.88
24	56	0	1.72	1.54	40	40	0	1.80	1.60
0	48	32	2.60	1.82					

Table VI gives the effect of salicylic aldehyde in cultures, principally potassic, similar to Table IV for the phosphate cultures and Table V for the nitrate cultures.

From this table it is seen that the aldehyde cultures are much smaller than the normal cultures. The total green weight of the 21 normal cultures was 47.67 grams against 33.74 grams for the cultures containing the salicylic aldehyde.

TABLE VI.—*Effect of salicylic aldehyde on wheat in nutrient culture solutions composed principally of potash.*

Composition of culture solution.			Without salicylic aldehyde.	With salicylic aldehyde, 10 parts per million.	Composition of culture solution.			Without salicylic aldehyde.	With salicylic aldehyde, 10 parts per million.
P ₂ O ₅	NH ₃	K ₂ O	Green weight.	Green weight.	P ₂ O ₅	NH ₃	K ₂ O	Green weight.	Green weight.
Parts per million.	Parts per million.	Parts per million.	Grams.	Grams.	Parts per million.	Parts per million.	Parts per million.	Grams.	Grams.
0	0	80	1.30	0.90	8	24	48	3.25	2.02
0	8	72	1.32	1.48	16	16	48	2.42	1.90
8	0	72	1.30	1.14	24	8	48	2.40	1.44
0	16	64	2.20	1.42	32	0	48	1.54	1.15
8	8	64	2.20	1.62	0	40	40	2.50	1.54
16	0	64	1.46	1.18	8	32	40	3.15	2.34
0	24	56	2.22	1.50	16	24	40	3.32	2.08
8	16	56	3.00	2.24	24	16	40	3.20	2.05
16	8	56	2.52	1.74	32	8	40	2.70	1.70
24	0	56	1.60	1.10	40	0	40	1.75	1.10
0	32	48	2.32	1.70					

The six cultures composed of approximately equal amounts of P₂O₅, NH₃, and K₂O is given in Table VII. The total green weight of the cultures in nutrient salts without salicylic aldehyde was 18.92 grams, and the total green weight for the cultures of similar composition with 10 parts per million salicylic aldehyde was 12.37 grams.

TABLE VII.—*Effect of salicylic aldehyde on wheat in nutrient culture solutions composed of phosphate, nitrate, and potash.*

Composition of culture solution.			Without salicylic aldehyde.	With salicylic aldehyde.	Composition of culture solution.			Without salicylic aldehyde.	With salicylic aldehyde.
P ₂ O ₅	NH ₃	K ₂ O	Green weight.	Green weight.	P ₂ O ₅	NH ₃	K ₂ O	Green weight.	Green weight.
<i>Parts per million.</i>	<i>Parts per million.</i>	<i>Parts per million.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Parts per million.</i>	<i>Parts per million.</i>	<i>Parts per million.</i>	<i>Grams.</i>	<i>Grams.</i>
32	16	32	2.94	1.86	24	24	32	3.68	2.04
32	24	24	3.12	2.30	24	32	24	3.00	2.00
32	32	16	2.84	1.97	16	32	32	3.34	2.20

From the foregoing results it is seen that salicylic aldehyde in amounts as small as 10 parts per million is harmful to the growth of wheat in nutrient solutions. In regard to the composition of the nutrient solutions affecting the harmfulness of the aldehyde it might be said that an analysis of the total green weights obtained in the case of the mainly phosphatic, the mainly nitrogenous, and the mainly potassic fertilizers given in Tables IV, V, and VI, respectively, shows that the least harmful effects are noted in the phosphatic group of cultures. This group as a whole shows a depression due to salicylic aldehyde of approximately 20 per cent in growth, while the other two groups showed approximately 27 and 29 per cent below the respective group of cultures without the aldehyde.

ABSORPTION OF NUTRIENT SALTS.

As salicylic aldehyde has been shown to be harmful to growth in culture solutions containing nutrient salts, it will be interesting to study its effect on the removal of nutrients from the solutions during the growth of the plant.

As stated above the concentration differences produced by the growth of the plants in the various cultures was determined by making an analysis for nitrates at the termination of every three-day change, and of phosphate and potassium on a composite of the solutions from the four changes.¹ It is possible, therefore, to compare the results obtained in the normal cultures without salicylic aldehyde and in the cultures where 10 parts per million of salicylic aldehyde were present in the solution.

The sum total of P₂O₅, NH₃, and K₂O removed from solution by the growing plants in all of the cultures under study was 1,646.6 milligrams in the normal cultures and 1,332.3 milligrams in the nutrient cultures containing salicylic aldehyde. The figures show the total of plant nutrients removed to be less in the cultures containing salicylic aldehyde than in the normal cultures, which indicates that the salicylic aldehyde cultures used less nutrients than the normal. The results of the examination of the three constituents separately are as follows:

¹ These determinations were made colorimetrically as described in Bul. 31 and Bul. 70, Bureau of Soils, U. S. Dept. of Agriculture.

Phosphate.—The amount of phosphate, stated as P_2O_5 , removed from the total number of solutions during the experiment was 395.7 milligrams for the normal cultures and 344.2 milligrams for the cultures containing salicylic aldehyde. The salicylic aldehyde cultures absorbed 51.5 milligrams of P_2O_5 less than the normal cultures.

Nitrate.—The total amount of nitrate, stated as NH_3 , removed from the total number of solutions during the course of the experiment was 578.3 milligrams for the normal cultures and 454.9 milligrams for the salicylic aldehyde cultures. The salicylic aldehyde cultures used 123.4 milligrams less nitrate.

Potassium.—The amount of potash, stated as K_2O , absorbed by the plants in the total number of cultures was 672.6 milligrams in the case of the normal cultures and 533.2 milligrams for the cultures with salicylic aldehyde. As with the phosphate and nitrate, the salicylic aldehyde cultures absorbed less potash, there being a difference of 139.4 milligrams in favor of the normal cultures.

An examination of the above figures shows a more nearly normal absorption of phosphate than of the nitrate or potash under the influence of the salicylic aldehyde. This would appear to be in harmony with the relatively lessened toxicity of the aldehyde in the mainly phosphatic nutrient solutions.

EFFECT OF CALCIUM CARBONATE ON THE ACTION OF SALICYLIC ALDEHYDE.

In order to study the effect of salicylic aldehyde under physiologically alkaline conditions, an experiment was made in nutrient culture solutions containing calcium carbonate. The cultures were prepared as in the experiments already recorded. The solutions were composed of calcium acid phosphate, sodium nitrate, and potassium sulphate in different proportions. Salicylic aldehyde was used in quantities of 10 parts per million, and 100 milligrams of calcium carbonate were added to each culture in the control set and in the salicylic aldehyde set. The plants grew from March 23 to April 4, 12 days. The solutions were changed every three days. The green weights of the plants grown in solutions without and with salicylic aldehyde are given in the fourth and fifth columns of Table VIII.

TABLE VIII.—*Effect of salicylic aldehyde in nutrient cultures containing calcium carbonate.*

Composition of nutrient solution.			Without salicylic aldehyde.	With salicylic aldehyde, 10 parts per million.	Composition of nutrient solution.			Without salicylic aldehyde.	With salicylic aldehyde, 10 parts per million.
P_2O_5	NH_3	K_2O			P_2O_5	NH_3	K_2O		
			Green weight.	Green weight.				Green weight.	Green weight.
Parts per million.	Parts per million.	Parts per million.	Grams.	Grams.	Parts per million.	Parts per million.	Parts per million.	Grams.	Grams.
48	16	16	2.85	1.95	8	64	8	2.70	2.45
64	8	8	2.00	1.95	16	16	48	3.55	2.55
16	48	16	3.19	2.45	8	8	64	2.60	2.05

These data show that salicylic aldehyde was harmful even in nutrient solutions containing an excess of lime. The growth in each culture with salicylic aldehyde was less than the corresponding culture which contained no salicylic aldehyde. The total growth of the six control cultures was 17.89 grams against 13.40 grams for the six salicylic aldehyde cultures. Putting the normal at 100, the salicylic aldehyde cultures become 75, a reduction in growth of 25 per cent.

In another test, involving a much larger number of cultures of varying composition, essentially the same result was obtained. In this case the growth was depressed 21 per cent as an average.

In the previous experiment, involving a larger number of nutrient solutions without calcium carbonate, growth was reduced 27 per cent by salicylic aldehyde, used in the same concentration as in the experiment with lime carbonate.

The roots of the plants were not as much stunted by the salicylic aldehyde in the presence of lime carbonate as they were in the experiment when no lime carbonate was used. The tops, however, were equally affected in the carbonate cultures. From these experiments under alkaline conditions it is seen that the harmfulness of salicylic aldehyde can in no wise be attributed to any slight acidity it may possess.

OCCURRENCE OF ALDEHYDES IN GARDEN AND FIELD SOILS.

The discovery of salicylic aldehyde with the harmful properties toward plants shown in the preceding section led to a study of the extent to which material of this type is likely to be encountered in soil investigations. In extending this study to many soils it was not feasible to examine large quantities of each soil, so that it was not possible to demonstrate clearly the identity of the aldehyde obtained, but it was possible so to treat a sample of soil as to obtain the compounds of an aldehyde nature contained therein, separated from compounds having nonaldehyde properties. This aldehyde material was tested as far as the quantity permitted for such reactions as are given by salicylic aldehyde, namely, coloration with ferric chloride, and the general aldehyde reaction with fuchsin reagent. In all cases the aldehyde was subjected to the physiological test as to its effect on plant growth, using wheat seedlings in the well-known manner. The procedure employed in extracting the aldehyde material from the soil and the manner of testing it was as follows:

Twelve to sixteen pounds of soil were used in the examination for aldehyde. The soil was extracted with 8 liters of a 3 per cent solution of sodium hydroxide. The solution was stirred for 6 to 8 hours and, after settling, the liquid was poured off. The alkaline extract was acidified with sulphuric acid and filtered from the so-called humus precipitate. The acid filtrate was shaken out with several

portions of ether, the ether extract combined and shaken with a concentrated aqueous solution of sodium bisulphite, which will remove aldehydes from the ether solution if present, by forming a water-soluble combination with the sodium bisulphite. The bisulphite solution was separated from the ether, strongly acidified with sulphuric acid, and air was blown through to remove the sulphur dioxide liberated. This acidified solution, in which the aldehyde is now liberated from its combination with the bisulphite, was then shaken with several portions of fresh ether, the ether extracts combined, and the ether removed by evaporation. There remained a small quantity of material, often resinous or oily in appearance.

This material was further purified by again taking up in water, extracting with ether, and the ether solution, after filtering, allowed to evaporate. Sometimes this operation was repeated. The purified residue contains the aldehyde material, if present.

This aldehyde material was treated with a small quantity of water. The aqueous solution is frequently colored, and on evaporation a yellow oil is often noticeable, as would be the case if salicylic aldehyde were present. The odor of the latter is also sometimes observed, although in other cases other odors are perceptible, suggesting other aldehydes.

The fuchsine reagent was added to a portion of the solution, and to another portion a small amount of ferric chloride was added. Salicylic aldehyde, as mentioned, gives a violet color with ferric chloride and a pink color with the fuchsine reagent. Where both these reactions were observed the soil was considered as containing aldehyde. While the nature of the material is not thereby definitely shown to be salicylic aldehyde, yet the manner of isolation with ether and extraction therefrom with sodium bisulphite, together with the reaction shown with the fuchsine reagent, show the material to be an aldehyde, and the physical character of fluidity and the reaction with ferric chloride make it quite probable that in most of these cases salicylic aldehyde was under consideration. The amount obtained did not permit of further identification than is here given, especially as the main object was to determine the physiological property of the extracted material.

The main portion of the material remaining after making the above tests was dissolved or mixed with 250 c. c. of pure distilled water and the resulting liquid used as a culture for wheat seedlings in order to test the physiological effect of the extracted material from the soil. This was done with every soil examined, whether the above tests were negative or positive.

In order to study the presence of aldehydes in soils a number of samples were tested. Included in this test were a number of soils sent to this bureau from time to time by gardeners and greenhouse

men. The soils submitted were garden and greenhouse soils, on which the owners had experienced some difficulty in producing vegetables or flowers. Often the soils had grown good crops, were intensively cultivated and heavily manured, and later failed. In this respect the conditions were similar to those on the Mount Vernon soil. This soil had been used for growing flowers and garden plants for a long period of years, had been intensively cultivated and heavily manured for a long time, had failed to show further response to manure, had been declining in productivity, and had been shown to contain salicylic aldehyde in the investigations reported. It seemed profitable therefore to include soils in this examination which in some degree had a similar history.

In addition to this adventitious examination of soil samples a similar survey was made with soils collected in the open field by the field men of this bureau under instructions furnished them. Accordingly, samples of field soils were collected from various parts of the United States. A productive sample and an unproductive sample of the same soil type, either from the same field or at least in the same vicinity, were sent in for investigation. The history of the soils as to crops grown, fertilization, drainage, etc., were secured as far as available.

The results of this examination for the occurrence of aldehyde compounds in soils include good and poor samples from many parts of the United States, comprising acid, neutral, and alkaline soils, soils of different cropping, different texture, origin, drainage conditions, climatic conditions, etc. The results of the examination of these soils will now be given.

A total of 74 soils are described in the two following tables. Of these 14 are garden and greenhouse soils which had failed to grow good crops and 60 are field soils under general farming conditions. Of these 60, 30 were productive soils and 30 unproductive. In this connection attention should again be called to the fact that the field samples were collected in pairs, one good and the other poor, of the same soil type and from the same field or locality, so that statements concerning productivity pertain to the relation existing between the samples of the same type.

These soils were all subjected to the method described for obtaining aldehyde compounds from soils and the material thus obtained tested with the reagents mentioned. Five of the garden soils and twelve of the field soils gave an appreciable amount of aldehyde compounds when thus extracted, and this material gave positive reactions with the fuchsin reagent and with the ferric chloride. These soils are briefly described in Table IX, together with the results obtained when the material was tested in the manner described with seedling wheat.

TABLE IX.—Soils in which aldehydes were demonstrated to be present.

No.	Soil.	Field record.	Location.	Crop on soil when sample was taken.	Reaction of soil.	Effect of extracted aldehyde material on growth of wheat.	Notes.
1	Garden soil, loam.		Mount Vernon, Va.	Flowers.	Acid.	Very harmful.	Rich loam, well manured for over a century.
2	Garden soil, silt loam.		Mechanicsburg, Pa.	Vegetables.	Very acid.	.....do.....	Poultry manure and commercial fertilizers used for 10 years.
3	Garden soil, red loam.		Orange, N. J.	.....do.....	Acid.	Slightly harmful.	Rich loam; declining. Heavy manuring ineffective.
4	Truck soil, red loam.		Chester County, Pa.	Truck crops.	Alkaline.	Very harmful.	Commercial fertilizers and rotation. Trucked for 20 years. Crops now failing. Soil contains excess of salts (0.15 per cent). Subsoil also contains aldehyde material.
5	Greenhouse soil, loam.		Arlington, Va.	Flowers.	Neutral.	.....do.....	Heavily manured.
6	Memphis silt loam.	Poor.	Lafayette County, Miss.	Grass.	Acid.	.....do.....	Pasture 20 years. No fertilizer.
7	Aurora silt loam.	Good.	Miller County, Mo.	Corn.	Slightly acid.	Harmful.	Manure occasionally. No fertilizers.
8	Norfolk very fine sandy loam.	.....do.....	Pender County, N. C.	Cotton.	Acid.	.....do.....	Well manured, occasionally fertilized.
9	.....do.....	Poor.	.....do.....	.....do.....	.....do.....	Very harmful.	No manure; 200 pounds commercial fertilizer.
10	Portsmouth silt loam.	.....do.....	Perquimans County, N. C.	Corn.	Slightly acid.	Harmful.	No manure; 200 pounds fertilizer.
11	Miami stony loam.	.....do.....	Oneida County, N. Y.	Meadow.	Acid.	.....do.....	Not fertilized.
12	Ontario loam.	.....do.....	.....do.....	Corn.	Neutral.	.....do.....	Stable manure.
13	Muskogee silt loam.	.....do.....	Muskegee County, Okla.	Cotton.	Acid.	.....do.....	No manure; no fertilizer.
14	Norfolk fine sandy loam.	.....do.....	Georgetown, S. C.	Corn.	.....do.....	.....do.....	Drainage poor.
15	Salt Lake clay.	.....do.....	Cache County, Utah.	Wheat.	Alkaline.	.....do.....	Manured.
16	Dekalb silty clay loam.	Good.	Preston County, W. Va.	Grass.	Slightly acid.	.....do.....	No manure; low-grade fertilizer used.
17	.....do.....	Poor.	.....do.....	Fallow.	.....do.....	.....do.....	

TABLE X. Soils in which no alkalies could be demonstrated.

No.	Soil.	Location.	Crop on soil when sample was taken.	Reaction of soil.	Effect of extracted material on growth of wheat.	Notes.
1	Garden soil, loam.	Washington, D. C.	Flowers.	Acid.	No effect.	Heavily manured.
2	do.	Pittsburgh, Pa.	do.	do.	Harmful.	Manured. Responds to lime.
3	Garden soil, gray sandy loam.	Philadelphia, Pa.	Garden crops.	do.	No effect.	Well manured. Salt content high.
4	Garden soil, loam.	Phoenixville, Pa.	do.	Alkaline.	do.	Drainage poor.
5	Garden soil, gray loam.	Philadelphia, Pa.	do.	do.	do.	Responds to lime and potash fertilizers.
6	Garden soil, waxy, black.	Green County, Ind.	do.	Acid.	do.	Soil had weathered for months since it had been used in flora culture.
7	Greenhouse soil, loam.	Arlington, Va.	Flowers.	Neutral.	do.	Poor raw soil used as basis for making greenhouse soil No. 7, this table, and No. 5, Table IX.
8	Greenhouse soil, raw soil.	do.	do.	Acid.	do.	Calcareous soil.
9	Dark-gray loam.	Sanford, Fla.	Citrus trees.	Alkaline.	do.	
10	Tifton sandy loam.	Covington County, Ala.	Corn.	Slightly acid.	Harmful.	
11	do.	do.	do.	do.	do.	
12	Huntington fine sandy loam.	Pope County, Ark.	do.	do.	Slightly beneficial.	
13	do.	do.	do.	do.	do.	
14	Decatur clay loam.	Chittlogua County, Ga.	Cotton.	Acid.	Not tested.	
15	do.	do.	do.	do.	do.	
16	Noesho silt loam.	Cherokee County, Kans.	Wheat.	Slightly acid.	Beneficial.	
17	do.	do.	Corn.	do.	do.	
18	Coby silt loam.	Jewell County, Kans.	do.	Neutral.	do.	
19	do.	do.	do.	do.	do.	
20	Osage loam.	Greenwood County, Kans.	Wheat.	do.	do.	
21	do.	do.	Grass.	Alkaline.	do.	
22	Do Kalb silt loam.	do.	Corn.	do.	do.	
23	do.	Christian County, Ky.	Clover.	Neutral.	No effect.	
24	do.	do.	Tobacco.	do.	Slightly harmful.	
25	Miami loam.	Genesee County, Mich.	Grass.	Slightly acid.	Harmful.	
26	do.	do.	Wheat.	do.	do.	
27	Carrington silt loam.	Goodhue County, Minn.	Barley.	do.	Beneficial.	
28	do.	do.	Grass.	do.	do.	
29	Memphis silt loam.	Lafayette County, Miss.	Corn.	do.	No effect.	
30	Summit silt loam.	Cass County, Mo.	Oats.	Not tested.	do.	
31	do.	do.	do.	do.	do.	
32	Aurora silt loam.	Miller County, Mo.	Wheat.	Slightly acid.	do.	
33	Freehold loam.	Monmouth County, N. J.	Grass.	do.	Beneficial.	
34	Dutchess silt loam.	Orange County, N. Y.	Corn.	do.	Slightly harmful.	
35	do.	do.	Millet.	Neutral.	do.	
			Grass.	do.	Harmful.	

36	Chandler loam.....	Good.	Ashe County, N. C.	Corn.....	do.....	No test.....
37	do.....	Poor.	do.....	do.....	do.....	do.....
38	Toxaway fine sand.....	Good.	do.....	Grass.....	Slightly acid.....	Harmful.....
39	do.....	Poor.	do.....	do.....	do.....	do.....
40	Portsmouth silt loam.....	Good.	Perquimans County, N. C.	Cotton.....	do.....	do.....
41	Miami stony loam.....	do.	Oneida County, N. Y.	Corn.....	Acid.....	Slightly harmful.....
42	Ontario loam.....	do.	do.....	Oats.....	Neutral.....	do.....
43	Muskogee silt loam.....	do.	Muskogee County, Okla.	Peanuts.....	Acid.....	Beneficial.....
44	Berks shale loam.....	do.	Lehigh County, Pa.	Grass.....	Slightly acid.....	No effect.....
45	do.....	Poor.	do.....	do.....	do.....	do.....
46	Norfolk fine sandy loam.....	Good.	Georgetown County, S. C.	Wheat.....	do.....	do.....
47	Clarksville silt loam.....	do.	Robertson County, Tenn.	Clover.....	do.....	do.....
48	do.....	Poor.	do.....	Oats.....	Acid.....	do.....
49	Jordan loam.....	Good.	Cache County, Utah.	Oats.....	Alkaline.....	Beneficial.....
50	do.....	Poor.	do.....	Wheat.....	do.....	do.....
51	Salt Lake Clay.....	Good.	do.....	do.....	do.....	Slightly harmful.....
52	Carrington silt loam.....	do.	Dane County, Wis.	Tobacco.....	Neutral.....	do.....
53	do.....	Poor.	do.....	Oats.....	Acid.....	Harmful.....
54	Sioux fine sandy loam.....	Good.	Buffalo County, Wis.	Corn.....	Slightly acid.....	No effect.....
55	do.....	Poor.	do.....	Rye.....	do.....	do.....
56	Miami silt loam.....	Good.	Jefferson County, Wis.	Corn.....	Neutral.....	Harmful.....
57	do.....	Poor.	do.....	Alfalfa.....	do.....	do.....

In Table X are given the remaining soils, which gave none or only an insignificant amount of extractive material when subjected to the method for obtaining aldehyde from soils, nor did this extract give the reactions with the above reagents. We must conclude therefore that the aldehyde material, salicylic aldehyde or other aldehydes, are either absent or present in much smaller quantities in the soils of Table X than in the soils given in Table IX.

From Table IX it will be seen that the soil aldehyde is in every case harmful to growth, and that all the soils behave in this respect like the Mount Vernon soil (No. 1), which has been already more fully described and in which salicylic aldehyde of poisonous properties was demonstrated.

In Plate V, figure 1, is shown the effect of this material from soil No. 2. This had been used for gardening and trucking for the last 10 years, and had been manured each year with poultry manure and commercial fertilizers. The soil in the last two years produced poor vegetables and truck crops, and corn failed entirely. The soil is grayish yellow in color, is quite acid and low in organic matter. The separated aldehyde extract was harmful to the growth of wheat seedlings, causing a decrease of 33 per cent.

In figure 2 of Plate V is shown the effect of the aldehyde extract from soil (No. 4), showing an alkaline reaction. This soil had been growing vegetables and truck crops for 20 years with frequent use of commercial fertilizers. Corn, cabbage, and cantaloupes had failed in certain sections of the field for the last two years, whereas formerly the soil grew excellent truck crops of all kinds. The soil and subsoil were quite alkaline to litmus paper, and both showed the presence of considerable aldehyde material. This aldehyde reduced growth of the test plants by 26 per cent, both tops and roots being severely injured.

The heavily manured greenhouse soil (No. 5, Table IX) is particularly interesting in that considerable aldehyde was found, whereas neither the raw soil (No. 8, Table X) nor similarly treated soil which had been used and then weathered for some time (No. 7, Table X) contained the harmful aldehyde material. This examination was made because the soil in question had been used on benches for floriculture and did not give good results. Soil No. 5, Table IX, was a composite taken from two benches in the greenhouse where carnations and roses did not thrive. This contained aldehyde, which, when tested with wheat seedlings, gave reductions in growth of 35 per cent. Soil No. 7, Table X, had been previously used for greenhouse purposes and had been made in the same way by manuring heavily the raw soil, but without experiencing any difficulty. Since then it had been in a pile outside for several months. At the time of testing no aldehyde could be found, nor was the residue

obtained harmful to the seedling wheat. Soil No. 8, Table X, was the raw soil as it was hauled from the field prior to the incorporation of manure in preparation for greenhouse use. No aldehyde could be detected in this soil, nor did such residue as was obtained show any harmful effect.

Soil No. 11, Table IX, the poor sample of Miami stony loam, contained aldehyde, and the depressed growth obtained is shown in Plate VI, figure 1, together with the effect of the identically extracted good field sample. The latter showed no aldehyde reactions, but as seen from the photograph it was, nevertheless, somewhat harmful—a fact which is recorded in Table X under No. 41.

Soil No. 12, Table IX, the Ontario loam, poor, from Oneida County, N. Y., together with its good companion sample, recorded as soil No. 42 in Table X, presents an interesting story. In 1907 both fields were poor, unproductive soils. Both fields were manured heavily every year. One field responded to this treatment, the other did not.

The field now good, represented by soil No. 42, Table X, grew corn in 1907 and produced a poor crop. In 1908 the field was manured and planted to oats, giving a good yield. It was manured every year after this. In 1909 and 1910 hay was grown with good results, the largest crop being in 1910. In 1911 an excellent crop of corn was grown, and in 1912 oats were again grown with good yields.

The other field represented by soil No. 12, Table IX, was in meadow in 1907 and gave poor yields. In 1908 the field was manured and planted to corn, which failed entirely. It was manured every year after this without good results. In 1909 oats were planted, but made very little growth. In 1910 and 1911 grass was sown and gave poor results. In 1912 the soil was heavily manured and again planted to corn. The yield of stover was very poor, and no grain was formed.

The laboratory examination of the two soils showed them to be neutral in reaction. The good soil gave no reactions for aldehydes when extracted for this purpose, but the extractive material was slightly harmful. The poor soil, however, gave considerable amounts of aldehyde material, and this was distinctly harmful to the wheat seedlings, reducing growth 28 per cent.

Soil No. 15, Table IX, the Salt Lake clay, is from a poor spot in an otherwise good field. The remainder of the field is represented by soil No. 51, Table X, and was collected about 35 feet from the poor spot. The color of the soil in the poor spot is light gray, while the good soil is gray with a pink tint. This spot is generally bare and seldom produces a crop, while the remainder of the field is very productive, yielding from 20 to 30 bushels of wheat per acre. The drainage in the poor spot is poorer than in the remainder of the

field. The subsoil of both good and poor soil is a light, calcareous clay. Both soils are alkaline in reaction, and both showed the same content of water soluble salts (0.03 per cent). The good sample contained no aldehydes, and such residue as was obtained proved only slightly harmful to wheat seedlings, whereas the poor sample contained considerable aldehydes, which proved very harmful to wheat seedlings in the cultural tests, reducing growth 30 per cent.

Returning now to a discussion of Table IX as a whole, it is shown that the aldehyde extract is uniformly harmful to the test plants. This is apparent from the next to the last column of the table.

In the third column is given the field record of the soils as to their productivity, the data being furnished by the collector. The garden soils already mentioned were all soils with which trouble of one kind or another had been experienced. In general, this column shows that the soils containing the aldehyde were also poor soils in garden and field, with some few exceptions. In this column is found one notable exception, in the Aurora silt loam, good (No. 7, Table IX), from Miller County, Mo. This soil contained aldehyde, whereas the corresponding poor sample (No. 31, in Table X), from another farm, gave no indication of the presence of aldehyde. This observation was confirmed by procuring a new sample from the farmer on the good soil six months later. The other exceptions are the Norfolk very fine sandy loam, good (No. 8, Table IX), and the Dekalb silty clay loam, good (No. 16, Table IX), in which aldehyde was found, but it will be noticed that in both these cases the poor soil contained the aldehyde also (Nos. 9 and 17, Table IX). It would appear therefore that both the good and poor soil samples contained some aldehyde. It might be further pointed out that in both cases the greater productivity of the sample designated as good is doubtless due to the direct fertilizing value of the applied manure, the less productive samples having no manure applied. That manure is not antagonistic to aldehyde is indicated by its presence in the exceedingly well-manured garden soils, in the same table (see notes in last column), as well as by some of the field results already given.

Some of the soils given in Table X, showing no aldehydes, have been discussed in connection with the preceding table. The remainder require no further discussion here, inasmuch as no aldehyde was found in either the good or poor samples.

From these two tables it is at once apparent that only a relatively small number of the poor soils showed the presence of aldehyde, which means that the pooriness of many of the soils in Table X must be attributed to other causes, since soil infertility may be due to a great many factors other than the presence of toxic compounds, and especially any particular toxic compound.

The material extracted in the aldehyde method was in all these cases extremely small and gave no aldehyde reactions, but in some cases it proved harmful nevertheless. What the nature of the harmful substance in these cases was it is impossible to state, as further study was excluded. If aldehyde was present, it was at least so small in amount that it escaped chemical detection, nor does the method wholly exclude the occurrence at this place of traces of other compounds. In the majority of cases the material was not harmful, occasionally even showing a slightly good or stimulating effect.

Seventy-four soils are described in the foregoing tables. Of these 14 were garden and greenhouse soils which had failed to grow crops, and 60 were field soils, under general farming conditions. Of these 60, 30 were productive soils and 30 unproductive. These soils were all examined for aldehydes. Of the 14 garden soils, five contained aldehydes, and of the 60 field soils 12 contained aldehydes.

(1) *In soils from widely different sections.*—The soils examined were from various parts of the United States; soils from 20 States make up the list. They vary from very unproductive to extremely fertile soils. Aldehydes were found in soils from nine States as widely separated as New York and Mississippi or Oklahoma. Its presence is therefore not confined to any locality.

(2) *In soils of different texture.*—The soils in which aldehyde occurred are not soils of any specific type or texture. The above list of soils containing aldehyde comprises clays, clay loams, silt loams, silty clay loams, loams, stony loams, fine sandy loams, and very fine sandy loams. There is therefore no apparent relation with soil type, or texture.

(3) *In unproductive soils.*—The unproductive soils examined can be divided into two classes: (1) Garden soils, comprising soils which have been highly fertilized and manured, heavily cropped and intensively cultivated, and later failed to produce good crops. This class includes several greenhouse soils. (2) Field soils, growing general farm crops with ordinary farm methods of cultivation.

Fourteen poor garden soils were examined, five of which contained aldehydes. All of these soils were very unproductive and failed entirely or grew very poor garden crops. Nine of the 30 unproductive field soils examined contained aldehydes.

(4) *In productive soils.*—Of the 30 productive soils examined three contained aldehydes. These were the Aurora silt loam, from Miller County, Mo.; Norfolk very fine sandy loam, from Pender County, N. C.; and Dekalb silt loam, from Preston County, W. Va.

(5) *In acid, alkaline, and neutral soils.*—It is interesting to note that some of the soils which contained aldehydes were acid, some neutral, and others alkaline. Three of the garden soils were acid, one

was alkaline, and one was neutral. Of the field soils which contained the aldehyde, ten were acid, one alkaline, and one neutral.

(6) *In soils growing different crops.*—Four of the soils which were found to contain aldehydes were garden soils and had been used for growing garden crops continuously for several years. One was a greenhouse soil and had grown carnations and roses. Twelve of the soils in which aldehyde was found were used for the growth of general field crops. A rotation of several crops was practiced on most of these soils. At the time the samples were collected three were in grass, four were growing corn, three were growing cotton, one was in wheat and one was fallow. These observations, together with the fact that no aldehydes were found on other soils growing the same crop, would seem to indicate that no close relation exists between the crop being grown and the presence of aldehyde.

EFFECT OF SALICYLIC ALDEHYDE ON COWPEAS, STRING BEANS, AND GARDEN PEAS GROWN IN THE FIELD.

The effect of salicylic aldehyde under field conditions was tested on plots at the Arlington Experiment Farm, Va. Three crops, cowpeas, string beans, and garden peas, were grown on the treated soil during the summer of 1913. Adjoining each plot growing a different crop, two check plots of equal size were planted with the same crop. The area of each plot was one-fourth of a square rod.

The soil on which the experiment was made is a heavy silty clay loam, low in organic matter. The land was plowed early in May and prepared for seeding with the above leguminous crops. Three applications of salicylic aldehyde were made, the first on May 20, one day before the crops were planted. The second application was made after the plants were up, on June 5, the third on June 24. Each application was at the rate of 35 pounds per acre, or 105 pounds per acre in all.

The salicylic aldehyde was applied by dissolving in water and sprinkling the solution uniformly on the surface of the land before planting and the soil cultivated thoroughly. After planting, the second and third applications were made by sprinkling the solution between the rows of plants, and the soil then cultivated.

All of the three crops germinated uniformly. The untreated check plots made the better growth from the very start. The effect of the salicylic aldehyde was noticeable throughout the experiment. The crops were grown to maturity and harvested.

EFFECT ON COWPEAS GROWN IN THE FIELD.

Both treated and untreated plots were sown to cowpeas on May 21, 1913, and the crop harvested on September 7, 1913. The cowpeas on the salicylic aldehyde treated plot were much stunted in growth.

The appearance of the plants on June 27 is shown in Plate VII, figure 1. The four rows of plants on the left are growing on the treated plot and the four rows on the right on an untreated plot. It is evident that the salicylic aldehyde is interfering with the proper development of the young plants. The effect became even more marked as the plants approached maturity. When mature, the peas were picked from the vines and weighed. After drying, the peas were shelled and measured. The vines themselves were cut and their weight taken. After curing, the weight of the dry hay was recorded. In Plate VII, figure 2, are shown the vines and peas as gathered from the check plot and from the salicylic aldehyde treated plot. The effect of the salicylic aldehyde in depressing crop yields is apparent.

In Table XI are given the results obtained in this experiment with salicylic aldehyde on cowpeas. The results are given as obtained from the individual plots and also in terms per acre:

TABLE XI.—*Yield of cowpeas as affected by salicylic aldehyde in the field.*

Treatment.	Yield per plot.			Yield per acre.		
	Vines.		Pods.	Vines.		Pods.
	Green.	Cured.		Green.	Cured.	
	Pounds.	Pounds.	Pounds.	Tons.	Tons.	Tons.
Check a.....	28.0	10.0	6.6	8.96	3.20	2.11
Check b.....	23.0	8.5	5.6	7.36	2.72	1.79
Average check.....	25.5	9.3	6.1	8.16	2.96	1.95
Salicylic aldehyde.....	16.0	4.3	3.5	5.12	1.38	1.12
Difference.....	9.5	5.0	2.6	3.04	1.58	.83

From the table it will be seen that the average yield of green vine and pods on the check plots was 10.11 tons, and on the salicylic aldehyde plot it was only 6.24 tons, making a total decrease of crop, 3.87 tons, or 38 per cent. The yield in pods alone was reduced 43 per cent, and in vines alone, 35 per cent. The cured hay, minus the pods, was reduced in yield as much as 1.6 tons per acre, a decrease of 50 per cent.

EFFECT ON STRING BEANS IN THE FIELD.

The string beans were less affected by the salicylic aldehyde than the cowpeas, and also less than the garden peas. The seeds were sown May 21; they germinated well, and a good stand was secured. As the crop grew it became apparent that there was a difference in the growth of the treated plots and the untreated, but it was not as marked as with the cowpeas. On July 22 the crop was harvested and the weight of green vine and beans obtained separately. The results are given in Table XII, and a photograph of the harvested crop is shown in Plate VIII, figure 1.

TABLE XII.—*Yield of string beans as affected by salicylic aldehyde in the field.*

Treatment.	Yield per plot.			Yield per acre.		
	Vines.	Beans.		Vines.	Beans.	
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pints.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pecks.</i>
Check <i>a</i>	3.55	1.90	4.75	2,272	1,236	190
Check <i>b</i>	2.94	1.66	4.15	1,882	1,062	166
Average check.....	3.24	1.78	4.45	2,070	1,149	178
Salicylic aldehyde.....	2.71	1.25	3.12	1,734	800	125
Difference.....	.53	.53	1.33	336	349	53

The average yield of vines and beans on the check plots was 3,219 pounds per acre, and on the salicylic aldehyde plot it was only 2,534 pounds, a decrease of 685 pounds of green matter per acre.

The yield of marketable bean crop was reduced 53 pecks per acre, or 30 per cent.

EFFECT ON GARDEN PEAS IN THE FIELD.

The garden peas were sown on May 21 and the matured vines and pods harvested separately on June 30 and weighed. A good stand was obtained. The plants showed from the start the effect of the salicylic aldehyde, and this became more pronounced with the other additions and as they neared maturity. Fruit formation was practically nothing on the salicylic aldehyde treated plot. The appearance of the treated and untreated plot on June 24 is shown in Plate VIII, figure 2. The harvested crops are shown in Plate VIII, figure 3. The weights and measurements obtained are given in Table XIII.

TABLE XIII.—*Yield of garden peas as affected by salicylic aldehyde in the field.*

Treatment.	Yield per plot.			Yield per acre.		
	Vines.	Peas.		Vines.	Peas.	
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pints.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pecks.</i>
Check <i>a</i>	1.72	1.66	4.50	1,101	1,062	180
Check <i>b</i>	1.50	1.48	4.00	950	947	160
Average check.....	1.61	1.57	4.25	1,030	1,004	170
Salicylic aldehyde.....	.52	.16	.43	333	102	17
Difference.....	1.09	1.41	3.82	697	902	153

The photograph and the table show conclusively the extremely harmful action of the salicylic aldehyde on garden peas. The yield of total plant material, vines and pods, was 2,034 pounds per acre as an average of the untreated checks, as compared with 435 pounds on the salicylic aldehyde plot, a decrease of 1,599 pounds. The marketable crop—that is, the peas in shell—was depressed from 1,004 pounds to only 102, or 90 per cent, practically a total failure.



FIG. 1.—EFFECT OF ALDEHYDE EXTRACTED FROM GARDEN SOIL (NO. 2, TABLE IX) FROM MECHANICSBURG, PA., ON GROWTH.

(1) Distilled water; (2) distilled water plus aldehyde.

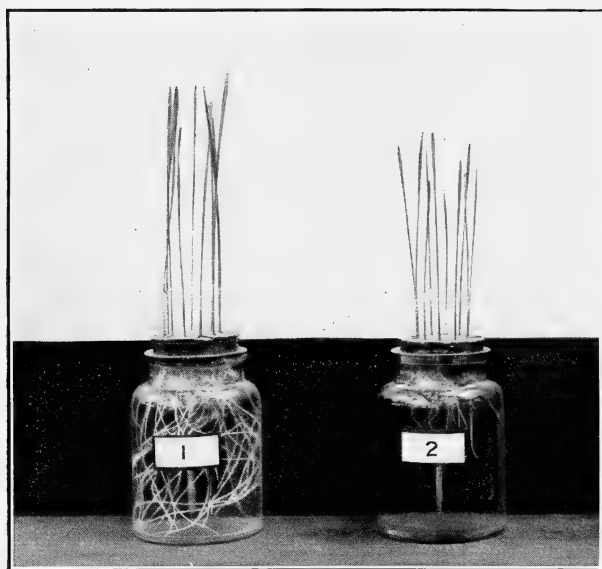


FIG. 2.—EFFECT OF ALDEHYDE EXTRACTED FROM A POOR GARDEN SOIL (NO. 4, TABLE IX) ON WHEAT SEEDLINGS.

(1) Distilled water; (2) distilled water plus aldehyde from garden soil.



EFFECT OF SUBSTANCE EXTRACTED FROM POOR AND GOOD MIAMI STONY LOAM (No. 11, TABLE IX, AND No. 41, TABLE X) ON WHEAT PLANTS.

- (1) Distilled water; (2) distilled water plus material from poor soil containing aldehyde;
(3) distilled water plus material from good soil showing no aldehyde reactions.

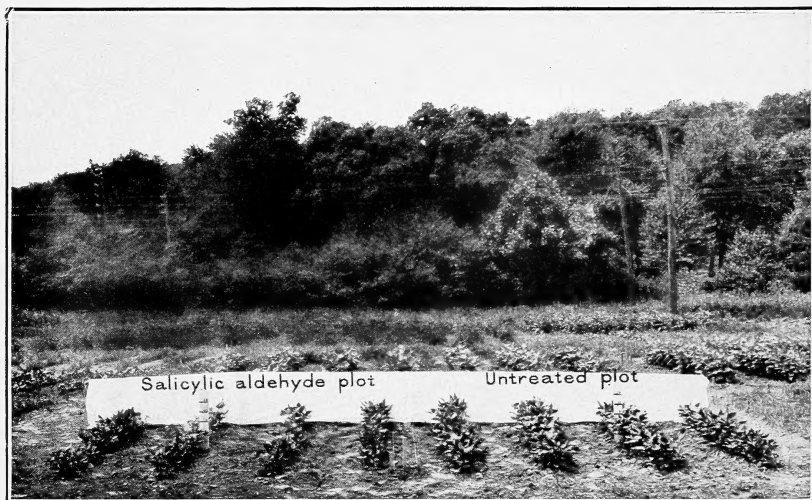


FIG. 1.—EFFECT OF SALICYLIC ALDEHYDE ON COWPEAS IN THE FIELD.

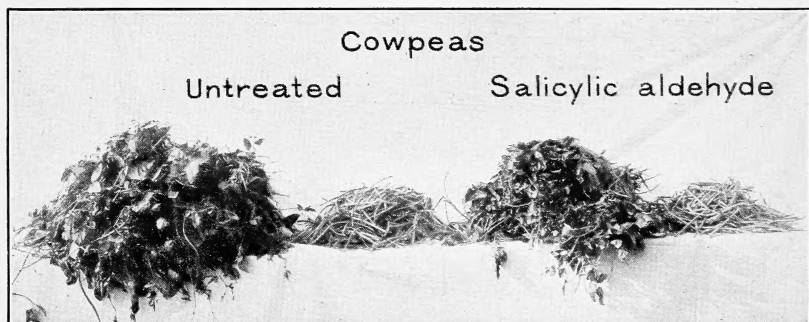


FIG. 2.—YIELD OF COWPEAS, VINE AND POD, ON CHECK PLOT *b* AND ON SALICYLIC ALDEHYDE TREATED PLOT.



FIG. 1.—YIELD OF STRING BEANS, VINE AND POD, ON CHECK PLOT *b*, AND ON THE SALICYLIC ALDEHYDE TREATED PLOT.

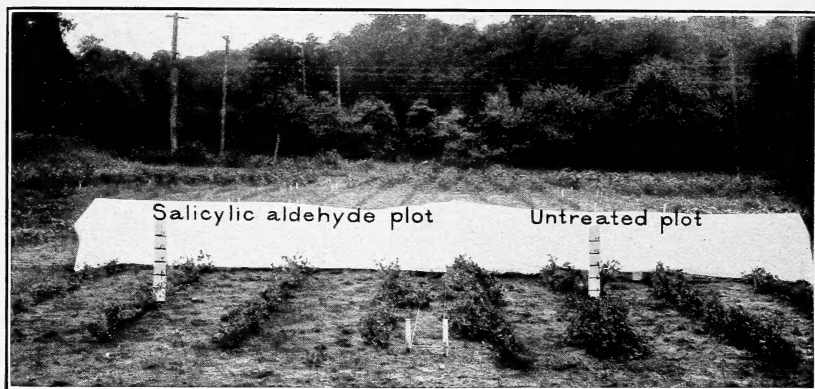


FIG. 2.—EFFECT OF SALICYLIC ALDEHYDE ON GARDEN PEAS IN THE FIELD.

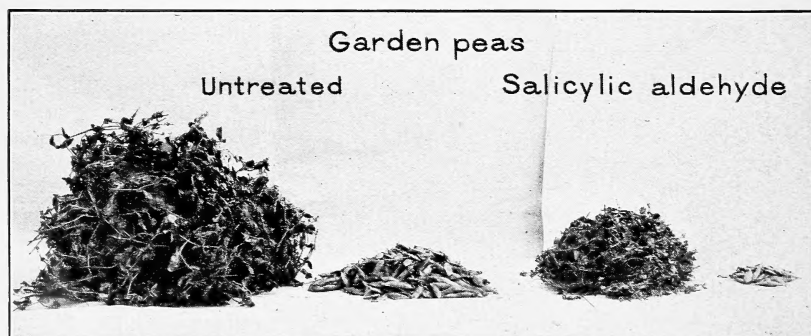


FIG. 3.—YIELD OF GARDEN PEAS, VINE AND POD, ON CHECK PLOT *b* AND ON THE SALICYLIC ALDEHYDE TREATED PLOT.

EXAMINATION OF THE FIELD PLOTS FOR ALDEHYDE SIX MONTHS AFTER APPLICATION.

That salicylic aldehyde can persist in some soils would seem to be indicated by the fact that the second shipment of Mount Vernon soil, collected six months later than the first, likewise contained salicylic aldehyde; also by the fact that the two samples of Aurora silt loam from Miller County, Mo., collected six months apart, both contained aldehydes.

In order further to verify this ability of the aldehyde to persist in some soils, the salicylic aldehyde treated field plots were subjected to an examination for aldehyde as had been done with the soil samples from garden and field described in preceding paragraphs. Soil samples were collected from the cowpea plots, the string bean plots, and the garden pea plots, i. e., one sample from each check plot and each salicylic aldehyde plot.

The six samples were examined for aldehyde. The three check samples contained none; the three treated plots showed the presence of aldehyde. The residues obtained in this procedure for separating aldehydes were tested with wheat seedlings, as described earlier in this paper. The extract from the check plots, which showed no aldehyde, grew plants as well as pure distilled water, whereas the extracted material from the aldehyde treated plots proved harmful to the wheat seedlings. The extract from the cowpea salicylic aldehyde plot decreased growth 32 per cent, that from the string bean plot decreased growth 27 per cent, and that from the garden pea plot decreased growth 26 per cent.

The existence of the harmful compound in the soil was also shown in another way by growing wheat in the greenhouse in paraffined wire pots, using the respective soils from the salicylic aldehyde treated plots and the check plots. Two pots, with six plants each, were used for each soil. The plants grew from December 11 to January 6. The results of this experiment are given in Table XIV. The table shows that the salicylic aldehyde in the soils of the treated plots six months after the salicylic aldehyde was applied was harmful to wheat.

TABLE XIV.—*Growth of wheat in soil taken from the field plots six months after treatment with salicylic aldehyde.*

Plot.	Wheat on soil from check plots.	Wheat on soil from salicylic aldehyde plots.	Relative growth, check=100.
	Grams.	Grams.	
Cowpea plot.....	1.48	1.18	80
String bean plot.....	1.54	1.11	72
Garden pea plot.....	1.47	1.22	83

A similar experiment was made with these soils, except that the crops grown in the pots were identical with those which had grown

in the field the preceding season, that is, cowpeas were grown on the cowpea soil from the check plot and from the salicylic aldehyde plot, string beans on the string bean soil from both the check and treated plot, and garden peas on the garden pea soil from both check and treated plot. Two pots were used in each case and two plants were grown in each pot. The plants grew from December 11 to January 6. The vegetative growth made in this experiment is given in Table XV.

TABLE XV.—*Growth of cowpeas in soil from the cowpea field plots, string beans in soil from the string bean field plots, and garden peas in the soil from garden pea field plots. Collected six months after treatment with salicylic aldehyde.*

Crop grown in pots in greenhouse and previously in the field.	Soil from check plots.	Soil from salicylic aldehyde plots.	Relative growth, check=100.
	Grams.	Grams.	
Cowpeas.....	4.30	3.80	88
String beans.....	7.80	7.20	92
Garden peas.....	5.60	4.30	77

The table shows that the salicylic aldehyde treated soil was still harmful to the respective crops in samples collected six months after the application of the salicylic aldehyde, the test plants growing about five months after the harvesting of the same crop in the field. It is also interesting to note that the relative order of toxicity shown toward the different crops is the same in these smaller vegetative experiments in the paraffined wire pots as in the case where the crops were harvested in the field. This would also seem to indicate that the observed order of toxicity toward these plants, namely, garden peas, cowpeas, string beans, may be more than accidental.

SUMMARY.

Compounds of an aldehyde nature exist in many soils. Such soils are usually unproductive. When separated from the soils, the aldehyde material is toxic to plants in pure water and in nutrient solutions.

One of these soil aldehydes is identified as salicylic aldehyde. This compound in very small amounts is harmful to plants in distilled water and in nutrient solutions. It is harmful to plants grown in pots of soil. It greatly decreases the yield of crops grown in the field. It persists in the field soils for months.

There is some evidence which suggests that lime and phosphate ameliorate the effects of salicylic aldehyde. Its chemical nature suggests that increased oxidation in soils under field conditions probably prevents its formation or accumulation.